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Location Identification Using a Magnetic-Field-Based FFT Signature

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Autonomous Agents in Ambient Intelligence

Abstract

User indoor positioning has been under constant improvement especially with the availability of new sensors integrated to the modern mobile devices. These sensory devices allow us to exploit not only infrastructures made for every day use, such as Wifi, but also natural infrastructure, as is the case of natural magnetic fields. In this work, we propose a novel approach that takes advantage of the benefits of using the magnetic sensor incorporated in most modern mobile devices, and the negligible variations of the Earth's magnetic field to position an individual with high accuracy. Most importantly, the methodology proposed allows us to avoid the burden of having to collect magnetic information in different directions in order to construct an accurate magnetic map, showing an improvement on methods that require the individuals to construct bigger magnetic maps that contain redundant information such as magnitude in different directions.

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1. Introduction

User positioning has been the focus of many research groups around the globe. Spatial awareness provides some insights about the needs of the users. In other words, user positioning is an essential element for most ubiquitous services. A vast amount of mobile applications have been deployed in the application markets, and a number of them rely on the context to offer customized services to the users. In a report published by Gartner [1], it is noted that Location-based services (LBS) consumers are expected to reach 1.4 billion users by 2014. This figure highlights the importance of having reliable location systems. On the other hand, applications of LBS are an interest option in indoor environments such as malls, schools, museums just to mention a few.

Localization plays a very important role in the future of mobile applications, especially those that rely on the context to provide the users with personalized services. For outdoor environments the estimation

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of the position of a user is typically estimated by means of GPS receivers. The problem is that in indoor environments, GPS is unreliable and many times unavailable.

Although many attempts have been made to reach higher degrees of accuracy [2], many of the approaches still rely on radio location infrastructures or expensive equipments. On the other hand, mobile phone localization [3] is becoming new in the field given the high availability of unexpensive mobile devices that carry numerous sensors that can be exploited to estimate the position of the individuals. Traditional indoor positioning systems (e.g. systems that use technologies such as Bluetooth, Wifi, RFID, etc.) have been diligently challenged by approaches that do not require costly infrastructures or that depend solely on natural signatures to locate a user. Among these approaches, we find those that make use of the natural magnetic fields for the purpose of estimating the position of an individual.

The aim of this work is to present a novel approach that exploits the capabilities of mobile phones through a specific sensory device, i.e., the magnetic sensor. In this paper we propose an algorithm that uses a magnetic-field-based Fast Fourier Transform signature to estimate the position of a user.

This research work addresses the problem of user localization by answering two questions: 1) Is it possible to estimate an individual's location by analyzing the magnetic field inside a building using a magnetic sensor included in a conventional mobile device? and 2) Is the location estimation independent of a predefined walking pattern taken by the user? In order to approach a feasible solution, we are required to collect and analyze measurements of the magnetic fields at different indoor places.

This paper is organized as follow. A description of related works for location estimation using different techniques is given in Section 2. In Section 3 we give a brief overview of the Magnetic Field Mapping technique. Section 4 presents an algorithm that uses a magnetic-field-based FFT signature to locate a user. Experimental procedures are described in Section 5. Section 6 shows the experimental results obtained after running the proposed algorithm. Finally conclusions and future work are presented in Section 7.

2. Related Work

Among the applications of magnetic field information in indoor environments, we can find the localization of a robot in an indoor environment [4]. In [5] an indoor localization method that exploits the Earth's magnetic field disturbances is proposed. In this research work, Chung et al. constructed a magnetic fingerprint map that is used to identify the location of the user's based on his/her magnetic fingerprint. The user's magnetic fingerprint is collected using a prototype device with 4 sensors, i.e., specialized hardware device.

A small portion of the proposed algorithms make use of the magnetic sensor found in most conventional mobile devices. For example, Gozick et al. [6] utilized two smartphones to study the magnetic fields in order to construct magnetic maps for indoor navigation. This work depicts the variations in the magnetic fields in a long-term.

In [7], Wang et al. use Wifi, magnetic sensors and accelerometers, encountered in most modern smartphones, to build an unsupervised indoor localization scheme. The main idea of this work is to delimit landmark locations using sensory devices, incorporated in most modern mobile devices, to position users.

Constandache et al. [8] propose a localization method that relies on the use of electronic compasses and accelerometers in mobile devices. The person's walking patterns are recorded and compared against path signatures generated by local electronic maps. The use of compasses and accelerometers limits the work by requiring devices to face certain directions in order to sense the environment.

3. Magnetic Field Mapping

The magnetic field of the Earth is commonly viewed as a large dipole magnet, describing the two opposing poles commonly referred as the north and south pole [9]. The natural magnetic field has three characteristics that suggest the feasibility of implementing a location system based on the natural infrastructure of the Earth's magnetic field.

First, the uniqueness of magnetic field variations from one location to the next in a building enables the development of a Magnetic-Field-Based location estimation algorithm. Second, given the fact that magnetic

fields are time invariant [10], i.e., they remain constant over long periods of time [10], the algorithm can use the signatures produced by magnetic field intensities along each room to locate an individual with decent accuracy. Third, the ambient geomagnetic field strength B can be modeled as a vector of three components B_x , B_y , and B_z [9], allowing us to compute the magnitude of the field as described in Eq. 1, where M_x , M_y , and M_z are the three physical axes along x , y , and z respectively.

$$|M| = \sqrt{M_x^2 + M_y^2 + M_z^2} \quad (1)$$

4. Location Estimation Algorithm

Every room in a building can be identified by a unique magnetic field signature since the variations are distinguishable from one another. In order to obtain the signature, it is required to collect magnetic information in different spots of the room.

After the signature has been precisely recorded, we eliminate spatial scaling and shifting by normalizing each signature using Eq. 2 where $z_{i,d}$ is the normalized reading, $r_{i,d}$ refers to the i^{th} observation of the signature in dimension d , μ_d is the mean value of the signature for dimension d and σ_d is the standard deviation of the signature for dimension d .

$$\forall i \in m : z_{i,d} = \frac{r_{i,d} - \mu_d}{\sigma_d} \quad (2)$$

Eq. 2 is applied for all dimensions in R^d

Given the similarity between a magnetic field signature and an audio waveform, we can depict the signature in terms of its energy information by performing a P-point Fast Fourier Transform (FFT) [11] to each signature, as shown in Eq. 3, where ES_i is the i^{th} energy signature of the normalized magnetic field, and NS_i is the i^{th} normalized magnetic field signature.

$$\forall i \in n : ES_i = FFT(NS_i) \quad (3)$$

The *energy signature* highlights an important aspect of our method since the transformed magnetic field signature becomes independent of time and walking patterns. In other words, we can avoid the burden of having to collect magnetic information in different directions in order to construct an accurate magnetic map.

In order to position an individual in the indoor environment, a magnetic fingerprint map is constructed a priori. The system compares the user's energy signature against the magnetic fingerprint map by applying a modified Manhattan distance given by Eq. 4, where the squaring assigns more relevance to the most significant frequencies. In other words, similar signatures must have small distance between them.

$$d(\mathbf{p}, \mathbf{0}) = \sqrt{\sum_{i=1}^n (p_i^2 - 0_i^2)} \quad (4)$$

5. Experimentation

5.1. Collecting Device

To avoid specialized sensors, the collecting device consists of an Acer A500 tablet with a built-in three-axis sensor with appropriate software applications to collect magnetic data.

The application is implemented in Java and makes use of Google libraries to obtain a link to the magnetic sensor of the device. The application collects data of the three physical axis x , y , and z of the magnetic field and stores them in the device for later processing.



Fig. 1. a) First floor house plans with furniture. b) Location of different rooms to be used for experimentation. Blue Livingroom, Red Dining room, Green Kitchen, Pink Bathroom.

5.2. Experimental Procedures

Experiments were performed at the ground floor of a residential home shown in Fig 1a. The open spaces in rooms were completely mapped in a period of time of about 10 seconds and they were independent of the walking patterns. Every room has different kinds of furnitures and distributions allowing us to have different magnetic signatures.

The experiments were performed in 4 rooms: kitchen, livingroom, bathroom and dining room, collecting the field strengths walking around the room during 10 seconds with the tablet at the waist with a average walking speed of 3.0 kilometres per hour. All the rooms are close to each other as it is shown in Fig. 1b. For each room, a total of four signatures were collected.

Each signature has 1000 readings, i.e., 100 readings per second. Then the magnitude was calculated for each reading using the equation 1, and following the proposed algorithm we proceeded to calculate z_i for all the signatures of the rooms.

In Fig. 2 we can see the signatures of the rooms after they were normalized. Once the normalization process was completed, the P-point FFT was performed on each signature. The energy signatures of each room are presented in Fig. 3. By observing the *energy signatures* we can conclude that they are similar, but to prove dissimilarity between signatures we randomly chose another signature for each room and analyzed the degree of dissimilarity using Pearson's correlation coefficient.

Table 1 shows that the existing correlation among the different rooms is less than 1. This correlation indicates that the signatures can be differentiated among themselves.

6. Experimental Results

From the previous signatures we randomly chose one for each room to be in a classification set of signatures, then the classification of the remaining signatures was done using the modified Manhattan distance shown in Eq. 4.

Table 2 shows that all the signatures were correctly classified even when the walking pattern are totally different.

Some signatures are very similar to other rooms, but we clearly can distinguish the correct one.

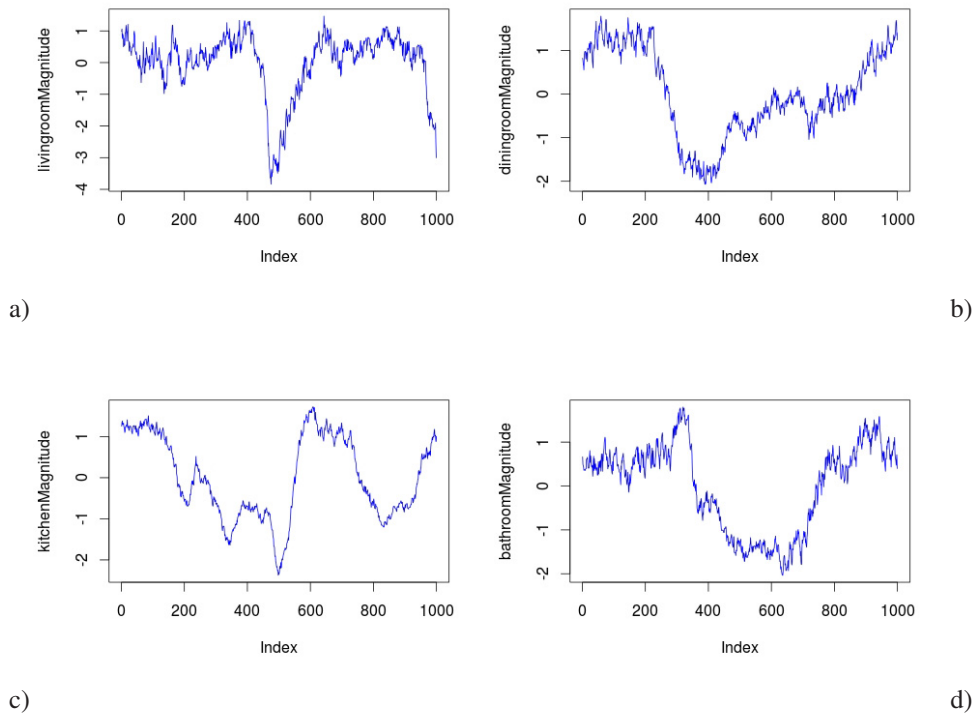


Fig. 2. Rooms signature after a normalization, a)Livingroom, b)Dining room, c)Kitchen, d)Bathroom

Table 1. Correlation Between Signatures For Different Locations

	Living Room	Dining Room	Kitchen	Bathroom
Living Room	1	0.6912992	0.8279071	0.6861144
Dining Room	0.6912992	1	0.7998618	0.9768714
Kitchen	0.8279071	0.7998618	1	0.7822493
Bathroom	0.6861144	0.9768714	0.7822493	1

Table 2. Signatures Classification For Different Locations

	Living Room	Dining Room	Kitchen	Bathroom
Living Room	3	0	0	0
Dining Room	0	3	0	0
Kitchen	0	0	3	0
Bathroom	0	0	0	3

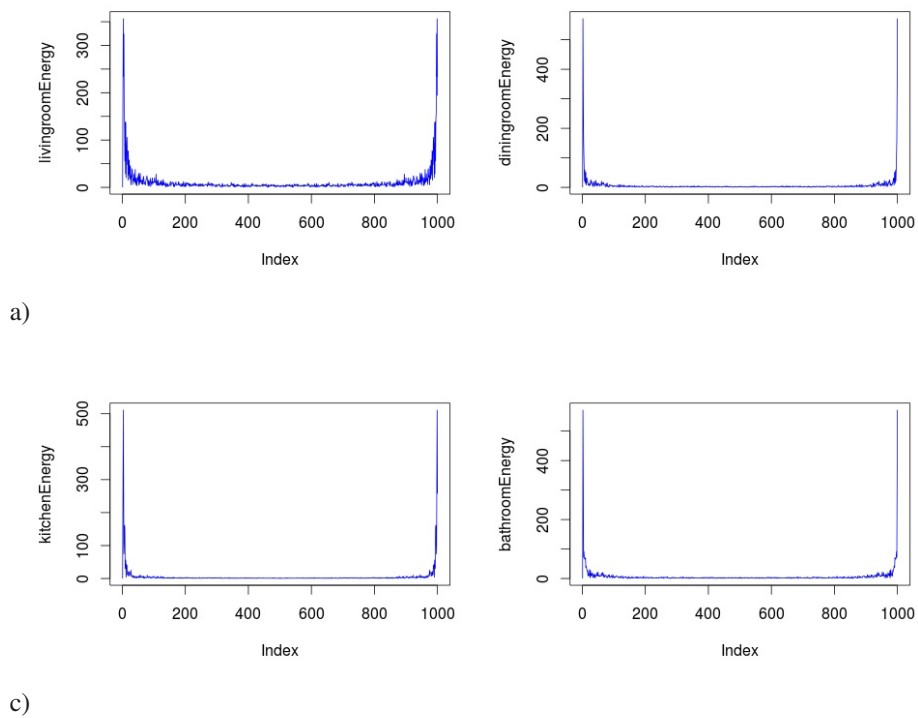


Fig. 3. Rooms energy signature, a)Livingroom, b)Dining room, c)Kitchen, d)Bathroom

7. Conclusions and Future Work

Indoor positioning is gaining importance given the amount of location based services that rely on it to offer customized services. The aim of this paper is to identify rooms in indoor environments independently of the time and the walking patterns followed by the individuals using magnetic signatures. Despite the variations, and the anomalies of the magnetic field inside buildings it is possible to identify a room with a magnetic field FFT signature. We have proposed a novel approach based on magnetic field localization technique that can be used to identify rooms inside a building having walking pattern independence using a non-specialized device or sensor. Future work consists in developing a robust algorithm to recognize an accurate location inside a room studying more complex pattern recognition techniques.

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